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Quarterly Progress Report, Jun 1992 – Aug 1992
ONR Contract Number N00014-91-J-1577
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Here is a quick look at some of the ideas we have been pursuing over this quarter:

• We have continued to refine the interpreter for our Reactive Plan Language (RPL). RPL plans make heavy use of concurrency. Wherever possible, we avoid imposing an arbitrary order on plan steps, and instead serialize them by having them compete for a kind of semaphore called a *valve*. A plan can request a valve using the RPL primitive VALVE-REQUEST; when it does, execution suspends until the valve is freed. What gets suspended is the local *process*, which corresponds to the piece of the task network that requested the valve. Processes form a hierarchy. If a task belonging to process P_0 executes a (PROCESS v a) form, the newly created process P_1 becomes an *immediate subprocess* of P_0, and the variable v is bound to it. Over time, an entire tree of processes develops, where each process corresponds (roughly) to a subtree of the task network.

Developing mechanisms for process management in RPL has been tricky. We want processes to interact with the task network in ways that don't arise in classical uses of concurrency. For example, a process for a subtask should be able to pre-empt a valve from the process for a supertask, because it is supposed to correspond to a part of the activity designed to accomplish the supertask.

Deadlocks can arise easily in this system, simply because of unforeseen consequences of combining modular plans. But plan transformations compound the problem. When a plan is transformed, new ordering relationships are likely to conflict with orderings imposed by valve requests. Here's an example:

```
(PARTIAL-ORDER ((PROCESS ONE
                    (VALVE-REQUEST ONE WHEELS NIL)
                    (STEP11)
                    (:TAG A (STEP12)))
                (PROCESS TWO
                    (VALVE-REQUEST TWO WHEELS NIL)
                    (STEP21)
                    (:TAG B (STEP22))))
   (:ORDER B A))
```

Suppose process ONE gets the wheels. When control gets to step A, process ONE will become wait-blocked waiting for step B to finish. But step B can't get started because process TWO is valve-blocked waiting for the wheels.

To compensate for the likelihood of deadlocks, we have designed (and redesigned) mechanisms for detecting cycles like this and breaking them. These mechanisms are put into play whenever a process becomes blocked. The interpreter looks for a *process cycle*, in which a series of processes are all waiting for each other, so that none will ever be able to proceed. Finding cycles requires searching through the process graph, so the interpreter tries to look for them only when it has to. When it finds one, it then looks for a process that could run if it were given all the valves it asked for. This algorithm works quite well in practice. It gets called only occasionally (when a process blocks or there are no threads to run). It has never failed to remove a deadlock, although one can construct cases that it can't handle.

• Visual Place Recognition: For reliable navigation, a mobile robot needs to be able to recognize where it is in the world. We have developed an efficient and effective image-based representation of perceptual information for place recognition. Each place is associated with a set of stored image signatures, each a matrix of numbers derived by evaluating some measurement functions over large blocks of pixels. We have demonstrated up to 90% recognition accuracy using this method alone. It may also be profitably combined with other recognition cues to improve accuracy. We are also addressing the problem that many signatures are inherently ambiguous, which bloats the database and makes recognition more difficult. This problem is ameliorated by using camera motion to select the best signatures

to use for recognition. We formulate several heuristic distinctiveness metrics which are good predictors of real image distinctiveness. These functions are then used to direct the motion of the camera to find locally distinctive views for use in recognition. This method was experimentally validated using a camera mounted on a robotic pan-tilt platform.

Activities:

Michael Beetz, July 13: Panelist at the Panel "Planning and Scheduling" (Workshop "Implementing Temporal Reasoning," AAAI-92

Michael Beetz, August: Talk on Improving and Debugging Reactive Plans that Contain Declarative Goals. German Research Center for Artificial Intelligence, Inc. (DFKI).

Michael Beetz, August: Improving and Debugging Reactive Plans that Contain Declarative Goals. Bavarian Research Center for Knowledge-based Systems (FORWISS), Germany.

Michael Beetz, - Improving and Debugging Reactive Plans that Contain Declarative Goals. Technical University of Darmstadt, Germany.

Greg Hager and G. Grunwald, Invited presentation on Sensor planning for reactive robot programs. Presented at the 1992 Allerton Conference on Control and Computing.

Drew McDermott, June 15–17: Chaired First International Conference on AI Planning Systems.

Drew McDermott, July 13–18: Taught at summer school on Temporal Reasoning in Bolzano, Italy, focusing on planning research.

Drew McDermott, Aug 13–14: Attended review of DARPA Transportation Scheduling Initiative, as a member of the Technical Review Board for that Initiative.

Publications:

M. Beetz, M. Lindner, and J. Schneeberger. Temporal Projection for Hierarchical, Partial-order Planning. To appear in: *Proceedings of ISAI-92,* AAAI Press.

Michael Beetz and Drew McDermott 1992 Declarative goals in reactive plans. In James Hendler (ed.) , *Proc. First Int. Conf. on AI Planning Systems,* San Mateo: Morgan Kaufmann, pp. 3–12

Sean P. Engelson and Drew McDermott, "Active Place Recognition Using Image Signatures", to appear in Proceedings of SPIE Sensor Fusion V, November 1992

Hager, G. D. Task-directed computation of qualitative decisions from sensor data. Submitted for review to the *IEEE Transactions on Robotics and Automation.*

Personnel Support:

We supported one graduate student, Sean Engelson, full-time during this period. Michael Beetz worked on the project for one summer month. Professors Drew McDermott and Greg Hager were supported for two months and one month, respectively, during the summer. In addition, we employed two part-time programmer, Amy Wang and Lee Chi-Wai, and a secretary, Paula Murano.

Expenditures:

The accompanying table shows the figures for expenditures to date, including amounts committed but not actually spent.

Overall Status and Plans:

We plan over the next few months to try to integrate the low-level sensor-planning aspects of our work with the higher-level planning aspects.

A crucial step in the development of our planner is to validate it by conducting experiments to see how much speedup planning gives us in our simulated world.

Per AD-A235020

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LEDGER DESCRIPTION	AMOUNT BUDGETED	COMMITTED (NOT PAID)	PAID TO DATE	TOTAL EXPENSES	REMAINING BALANCE
FACULTY SALARY	33,223	11,388.89	38,988.67	50,377.56	-17,154.56
CLERICAL & TECHNICAL	16,560	10,507.75	20,143.84	30,651.59	-14,091.59
STUDENT ASST.	88,050	7,753.77	24,646.37	32,400.14	55,649.86
OTHER YALE STUDENTS	0		15,632.	15,632	-15,632.
DIRECT WAGES	0	344.00	344.	-344.	
EMP. BENEFITS	18,123.	7,203.86	18,330.56	25,534.42	-7,411.42
D/P SUPPLIES	0	459.	2,658.78	3,117.78	-3,117.78
D/P SVS.	24,840	11,200	14,231	25,431.	-591.
MINOR EQUIPMENT	0	00	379.	379.	-379.
MISC MATERIALS	0		55.17	55.17	-55.17
D/P SOFTWARE	6,000	00	2,633	2,633	3,367
FREIGHT & TRANSPORTATION	0	68.50	448.72	517.22	-517.22
PHOTOCOPYING	4,140	51.11	1,546.86	1,597.97	2,542.03

LEDGER DESCRIPTION	AMOUNT BUDGETED	COMMITTED (NOT PAID)	PAID TO DATE	TOTAL EXPENSES	REMAINING BALANCE
PRINTING	0		313.80	313.80	-313.80
MISC SERVICES	0		270	270	-270
COMMISSIONS	0		25.	25.	-25.
D/P EQUIPMENT MAINT	0		372.	372.	-372.
TRAVEL (DOMESTIC)	8,280	503.42	7,397.84	7,901.26	378.74
TRAVEL (FOREIGN)	0		2,913.98	2,913.98	-2,913.98
OFFICE SUPPLIES	2,070	102.21	702.95	805.16	1,264.84
PERIODICALS	0		1,162.45	1,162.45	-1,162.45
POSTAGE	0	112.85	542.55	655.40	-655.40
TUITION REMISSION	44,532	5,306.64	13,476.	18,782.64	25,749.36
HEALTH INS.	0	540	585.	1,125.	-1,125.
TELEPHONE	2,070	201.19	301.99	503.18	1,566.82
DATA PROC. EQUIPMENT	139,000	36,418.25	38,538	74.956.25	64,043.75
INDIRECT (OVERHEAD 68.0%)	138,282	34,062.93	105,145.31	139,208.24	-926.24
TOTAL:	525,170	125,880.37	311,784.84	437,665.21	87,504.79
		OVERHEAD ANTICIPATED:			35,418.61
		SPENDING BALANCE AVAILABLE AS OF 09/18/92:			52,086.18